

# **Measurements of Turbulence in the Upper Layer with AUTOSUB**

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## **LONG-TERM GOALS**

The long term goal is to understand the dynamics of the upper layer of the ocean.

## **OBJECTIVES**

This grant covers measurements made in conjunction with Drs. Steve Thorpe and Rolf Lueck using AUTOSUB equipped with side scan sonars and turbulence probes to examine and quantify the following phenomena:

1. the intensity, structure and decay of turbulence beneath breaking wind waves, graded according to their acoustic scattering on breaking, in different wind, buoyancy flux, and swell conditions, to provide the information necessary to construct a model of turbulence generated by breaking waves (in the presence of a buoyancy flux), in particular to assess its effects on turbulence production in the mixed layer and transport of momentum and heat. Presently, little is known even of the vortex structure/rotors produced or the persistence of turbulence beneath breaking waves (Thorpe 1995).
2. the variation of turbulence levels within and between the bands of bubbles associated with Langmuir circulation, to establish the role of Langmuir circulation in the vertical transport of heat and momentum, comparing their effects with that of breaking waves, with the objective of improving their representation in models of air-sea transfers and the mixed layer; and
3. the variation in upper ocean turbulence resulting from internal gravity waves to establish the effect of internal waves on turbulence in the upper ocean (by, for example, the stretching of vortex lines - see Thorpe, 1996).

To achieve these objectives, AUTOSUB was operated in open waters of western Scotland.

## **APPROACH**

AUTOSUB (figure 1) is funded by the Natural Environment Research Council of the United Kingdom and the operations are located at the Southampton Oceanography Centre. The vehicle is a 6.8 m long, 0.9 m in diameter, and weighs 3400 pounds in air. Propulsion is from a brushless DC motor that uses rare earth magnets on an external rotor that holds the five blades of the propeller. The present range is

70 km (soon to be extended to 1000 km) with an endurance of 50 hours (soon to be extended to 150 hours). It is presently capable of 250 m depth but can operate at 2 m depth. Operational depth will be increased to 2500 to 5000 m. Cruising speed depends on instrumentation with a nominal value of 2



*Figure 1. Top panel is AUTOSUB underway for near surface test in Loch Linnhe Scotland. The lower panel shows the turbulence pressure case covered with the retractable sheath that protects the delicate probes when the vehicle is on the surface.*

m/s for a clean configuration and a speed of 1.3 m/s for our present configuration. The vessel operates very smoothly with r.m.s. values 0.04 m for depth,  $0.2^\circ$  for pitch,  $0.2^\circ$  for yaw, and  $0.4^\circ$  for roll. To achieve the mission objectives, AUTOSUB is equipped with (a) ARIES II control and sonars (250 kHz at 2 Hz scan rate), (b) turbulence sensors, (c) CTD - at least 2 Hz recording (for detection of fronts, etc), and (d) 300 kHz ADCP. The CTD and ADCP are part of the normal instrumentation complement on AUTOSUB.

The turbulence instrumentation that are used in this project were originally designed and developed for the work on the USS Dolphin. The digitization rate is 512 Hz and the analog filters on the data channels cut off sharply at 200 Hz. The data is digitized by, and stored in, a small computer which is located inside AUTOSUB. This technology enables us to digitize and store 200 hours worth of data. Power comes from the AUTOSUB. A timing signal comes from the ARIES II package in order to assure alignment between the two data sets.

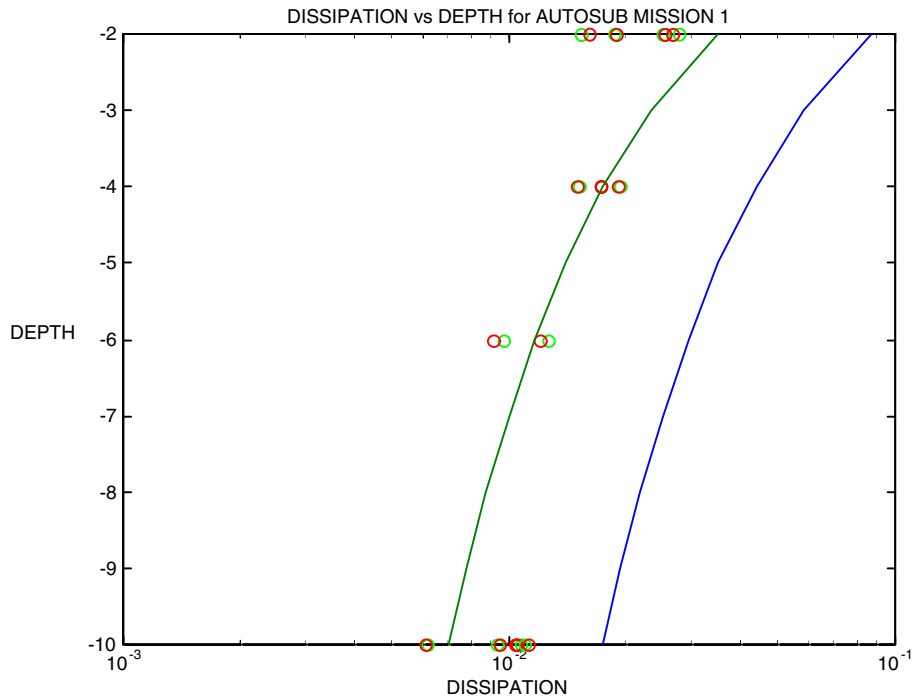
There are eight channels of data: two shear probes (one measuring the cross stream horizontal velocity fluctuations and the other the vertical velocity component) , temperature, temperature derivative, three accelerometers (for pitch, roll and heave), and pressure combined with the pressure derivative. The shear data are be used to calculate dissipation rate. The temperature and temperature derivative data can be combined and digitally filtered (Osborn et. al., 1992) to produce high resolution temperature traces with resolution of millidegrees. This data offers the potential of calculating the turbulent heat flux just below the sea surface (Yamazaki and Osborn, 1993). The pressure and its derivative can be filtered to produce a pressure record with sufficient resolution to resolve the wave spectra.

## **WORK COMPLETED**

Measurements were made at depths of 2, 4, 6 and 10 m in four missions with data collection of over 100 hrs in winds from calm to 13 m/s, with straight runs in two directions at right angles to one another, each for periods of about one hour. Fetch was generally limited to about 20 km. The data return has been excellent and analysis was begun on shore even while data was still being collected.

## **RESULTS**

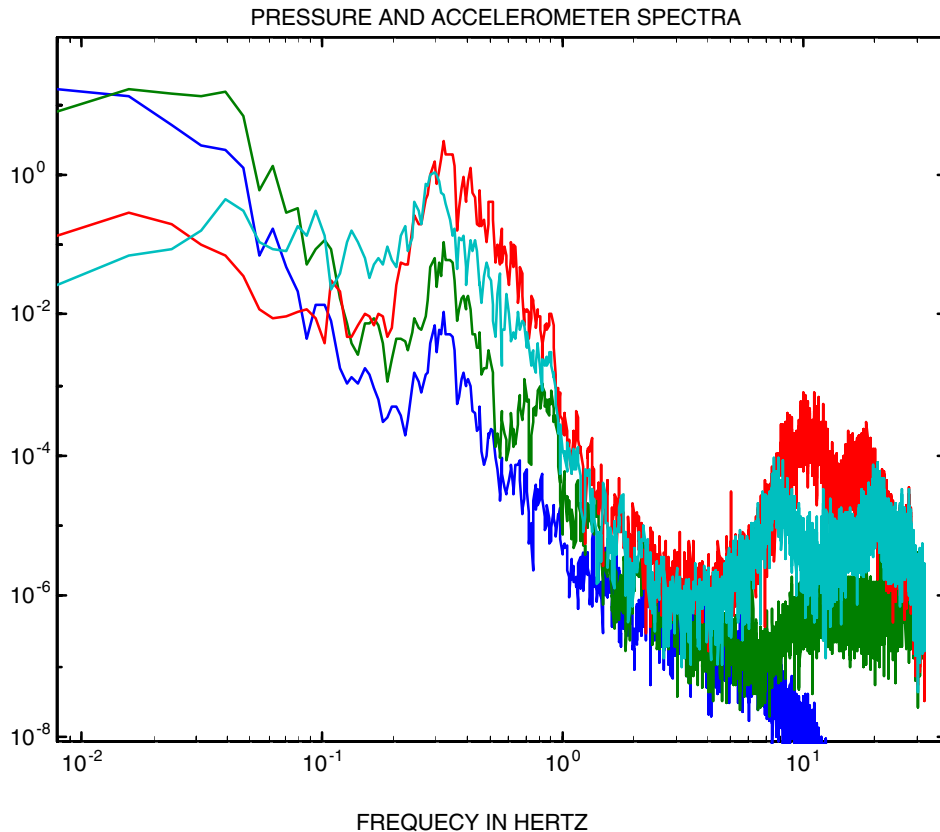
The first interesting result is that the dissipation profile with depth falls well below the “law of the wall’ rather than above it as has often been seen previously (Osborn et. al., 1992). Figure 2 shows the means dissipation from each leg of the sampling in Mission 1 calculated from both the measured shear components. The two channels agree very well, however, the dissipations are below the values calculated from the law of the wall (calculated using the local wind speed of 11.3 m/s) by a factor between 2 and 3. This situation is possibly due to the divergence of the wave momentum. The region has limited fetch (20 km) and the wave field is growing so a possible explanation is that the divergence of the wave momentum reduces the stress applied to the water column although that factor should be relatively small.



**Figure 2** Dissipation (in  $\text{cm}^2/\text{s}^3$ ) versus depth from Mission 1, averaged over the 2 km long sides the square track pattern followed by AUTOSUB. Red and green circles are the data from the two channels (which agree quite well). The blue line represents  $u_*^3 / \kappa z$  based on the measured wind speed of 11.3 m/s, while the green line represents 40% of those values. The dissipation is significantly lower than expected from the law of the wall.

Other results come from the conditional sampling and statistical averaging of the data. This process has identified temperature anomalies associated with bubble clouds. Further analysis of this data set will distinguish clouds which are aligned in Langmuir bands from those of known age caused by recently broken waves. Joint measurements with David Farmer and Steve Thorpe investigate the ageing of bubble populations and their relation to turbulence with a view to improving models of turbulence in the upper ocean.

Figure 3 shows the pressure and accelerometer spectra from a four minute period during the first leg of Mission 1. The pressure spectra come from a signal that is a combination of the pressure and pressure derivative signal (Osborn et. al., 1992 using the method of Mudge and Lueck, 1994). The wave motion induces signals in both the pressure and the accelerometers. Knowing the speed and direction of the vehicle, and assuming the waves are aligned with the wind direction (sampled by the surface vessel), the spectra in figure 3 enable us to estimate the period of the major waves. Since the vehicle is close to neutrally buoyant, in the vertical it responds to the wave induced pressure force (which accelerates the water for the wave) and hence, the waves show up well in the accelerometers. This data will receive further analysis.



**Figure 3.** *Spectra of pressure signal (dark blue), longitudinal acceleration (direction of travel, called  $A_x$ , in green), vertical acceleration (called  $A_z$  in red), and lateral acceleration (called  $A_y$  in cyan). Units on the pressure are  $m^2/Hz$ . Units on acceleration are  $(m/s^2)^2/Hz$ . Note the wave motion is just above 0.3 Hz in this data from Mission 1 at 2 m depth. The spectra are produced from the original data after averaging by 8 which reduces the Nyquist frequency to 32 Hz.*

## IMPACT/APPLICATIONS

The development of a long range, autonomous capability to sample turbulence in the surface and near surface regimes of the upper ocean in difficult weather conditions is vital to understanding the important and complex processes that occur there.

## TRANSITIONS

The technology for turbulence measurements and interpretation that has been developed by the PI through ONR funding during the last 25 years is now well established in the oceanography community.

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